IMPROVED UNDERSEA TOWING CABLE

Phase I SBIR
Final Report

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by

Cortland Cable Company

and the

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Part A - Temperature Profiler

Prototype Thermistor Cable Design

During the course of development work several specific manufacturing tasks that would be necessary to successfully fabricate a cable with embedded sensors were identified. The exercise of building a prototype cable would provide the opportunity to assess the feasibility of accomplishing these tasks.

Proposed Cable Components

A meeting was held at Cortland Cable Company on April 16, 1997, to discuss the proposed design for a prototype temperature profiling cable. At this meeting a plan was formulated to build a nominal 500 ft long cable with one or two fiber optic Bragg gratings and enough small insulated conductor pairs to support as many thermistors as possible. These are the basic components planned for the cable:

Center strength member consisting of 3,000 lbs minimum breaking strength Vectran fiber core with a Surlyn jacket to a nominal diameter of 3/16".

Profile extruded inner jacket with two slots, one for each of two optical fiber leads from fiber optic sensors.

Two fiber optic Bragg gratings furnished by NRL - one with a long lead (400 ft) and the other with a short lead (100 ft).

At least twelve pairs of small gage insulated wire leads in a served construction using a braider to keep them evenly spaced around the circumference of the cable.

At least twelve thermistors, Thermometrics P/N BR14PA103N miniature temperature sensors with the following characteristics:

BR: Bead, ruggedized
14:   Sensor diameter of 0.014"
P: Leads at opposite ends of bead sensor
A: Material code designating 7.5K - 15K ohms
103: 10^3 ohms resistance @ 25°C
N: 25% tolerance on resistance variation

Extruded outer jacket. Hytrel may be preferred over polyurethane for its lower coefficient of friction, making it easier to wind on the drum.

Strength Member

A nominal half inch diameter jacketed strength member core was initially considered for the central member of the prototype cable. However, since the strength requirement for this cable was fairly low and there was potential interest in putting the cable into a pressure vessel for calibrating the thermistors, we opted to use a smaller diameter core for our prototype.

Profile Extrusion

In order to protect the fiber optic leads to the optical sensors from mechanical damage in the cable, special extrusion tooling was ordered that would enable the fabrication of a jacket with two grooves in it. The plan was to extrude a protective sleeve over each fiber to a nominal 0.040" diameter, so the slots in the cable jacket were 0.040" wide and 0.040" deep. When this slotted sleeve was extruded, the urethane tended to shrink a bit, which resulted in the slots being undersize.

Fiber Optic Sensors

NRL offered to provide us one usable fiber optic Bragg grating, at no charge, with the request that they have an opportunity to test the cable with the embedded sensor. Providing the sensor with a long fiber optic lead was a problem, for the type of fiber in which the Bragg gratings are etched is very expensive. Therefore, the technician at NRL made a standard fusion splice to a section of standard singlemode fiber and sent us the result. The fusion splice was rather bulky. It included the steel splint and heavy shrink tube designed to protect the joint from breaking. This large splice would make the sensor assembly difficult to incorporate into a cable without a noticeable lump. Such an irregularity in the cable profile would not stand up well to winding on and off a cable drum or winch.

It was therefore necessary to look for other temperature sensing technologies that might be compatible with our application. F & S (Fiber & Sensor) Technologies of Blacksburg, VA, offered three different optical sensor concepts to consider. One is the OTDR-based approach, the second is referred to as the EFPI (extrinsic Fabry-Perot interferometric) optical fiber sensor and the third device is called a Bragg grating sensor. The one that F&S felt had the best chance of working that they could provide with a short lead time was the EFPI sensor. A purchase order was issued and F&S quickly responded by sending four fiber sensor assemblies.

One of the immediate concerns that using these components presented was the lack of any method for verifying their integrity as we went through the build process. There were three or four discrete manufacturing operations that might pose a threat to delicate fiber optic elements. In the event of a failure, it would not be possible to identify which operation was the cause. In fact, the fiber could be broken during an early stage of fabrication and the damage would not be discovered until the cable was finished.

As received, the EFPI sensors were connected to a very fine diameter fiber (less than 0.007") which would be very difficult to process successfully without risk of damage. Therefore, one possible remedy was to apply an extruded sleeve of Hytrel over the fiber (and the sensor) to make it a little more rugged. In order to do this, the extrusion tip would need to be large enough to allow the sensor to pass through. The stainless tube protecting the sensor has a diameter of about 0.040". Before committing the expensive sensors to the extrusion process, some simulated assemblies were fabricated by sliding a one millimeter stainless tube over some spare optical fiber and gluing it in place. These dummy fiber assemblies were used for some extrusion trials. The pressure tooling did not work because the molten plastic would backfeed into the tip alongside the optical fiber. Once that plastic got far enough away from the active heating of the extruder it would harden and grab the core causing it to break. Tube tooling was tried as an alternative and this resulted in a sleeve that did not draw down concentrically over the fiber. When neither tooling configuration resulted in a successful extrusion, this approach to protecting the fiber was abandoned.

It would be unwise to try to incorporate the tiny fiber unprotected, so the spool of fiber was set up to feed into a copper stranding machine with some parallel Kevlar 49 strength reinforcement. Ten strands of #34 awg bare copper were spiraled around the parallel core elements to hold them together and give the reinforced fiber optic strand a circular cross-section.

Fine Wire Leads

The baseline conductor leads used in the prototype cable were #30 awg Teflon insulated wire in a variety of colors which facilitated a design with distinctly color-coded pairs. Some smaller gage wires were included as part of the prototype to evaluate the theoretical limit of what was processible in manufacturing and workable electrically in the thermistor circuit. These smaller wires included some #32 awg wires and three XBT pairs (two isolated #39 awg copper strands with a tough, thin film coating). These smallest wires did not have enough strength on their own to lift the braider latches during the stranding operation, so the XBT wires were wound in parallel with other elements to provide reinforcement. One XBT was wound with a strand of Kevlar yarn, one with polyester yarn and the third was wound along with a pair of the larger conductors. This last approach made it theoretically possible to strand two pairs per bobbin and support twice as many sensors.

Thermistor Sensors

Thirty-six sensors were ordered for the prototype cable and additional laboratory testing. When these sensors arrived inspection revealed that they did not have the heavier leads and thin wall shrink tubing that was had expected. In fact the leads were less than a half inch long and the wire diameter was about one thousandth of and inch (0.0011"). These sensors were returned to Thermometrics to have them attach #38 awg lead wires (0.004") and a protective shrink tube. The result was a component that could be seen without squinting, which made the installation less of an ordeal. A 2X magnifier lamp was used to aid in the attachment process.

Thermistor Lead Wire Pattern

BK/BL(#32)
OR/BK
BR/S
GY/XBT
BR/G
S/G
OR/BR
OR/XBT
+BL(#32)
KY/XBT
S/Y
Y/OR
BL/G(#32)
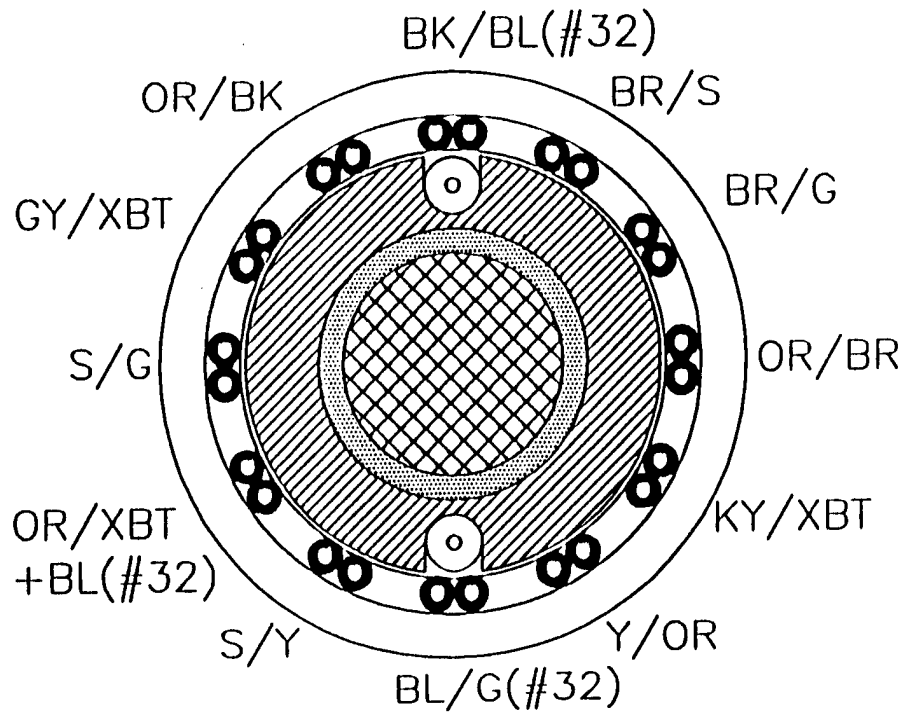
BR=BROWN   BK=BLACK

OR=ORANGE   BL=BLUE #32 AWG

Y=YELLOW   KY=KEVLAR YARN

G=GREEN   GY=GREEN PET YARN

S=SLATE (GRAY) XBT=PR OF #39 AWG

Outer Jacket

Hytrel was selected as the jacket material for several reasons. A bondable material was needed in order to mold the cable closed after connecting all the leads. Since there were to be embedded optical fibers in the cable, a stiff resin would help to limit bending and therefore offer additional protection for the fiber optic elements. The jacket wall thickness was approximately 0.060". When winding the cable on a drum, polyurethane tends to be tacky and climb on itself, rather than laying flat across the layer of wraps. Hytrel has a harder, smoother surface which makes the winding task easier.
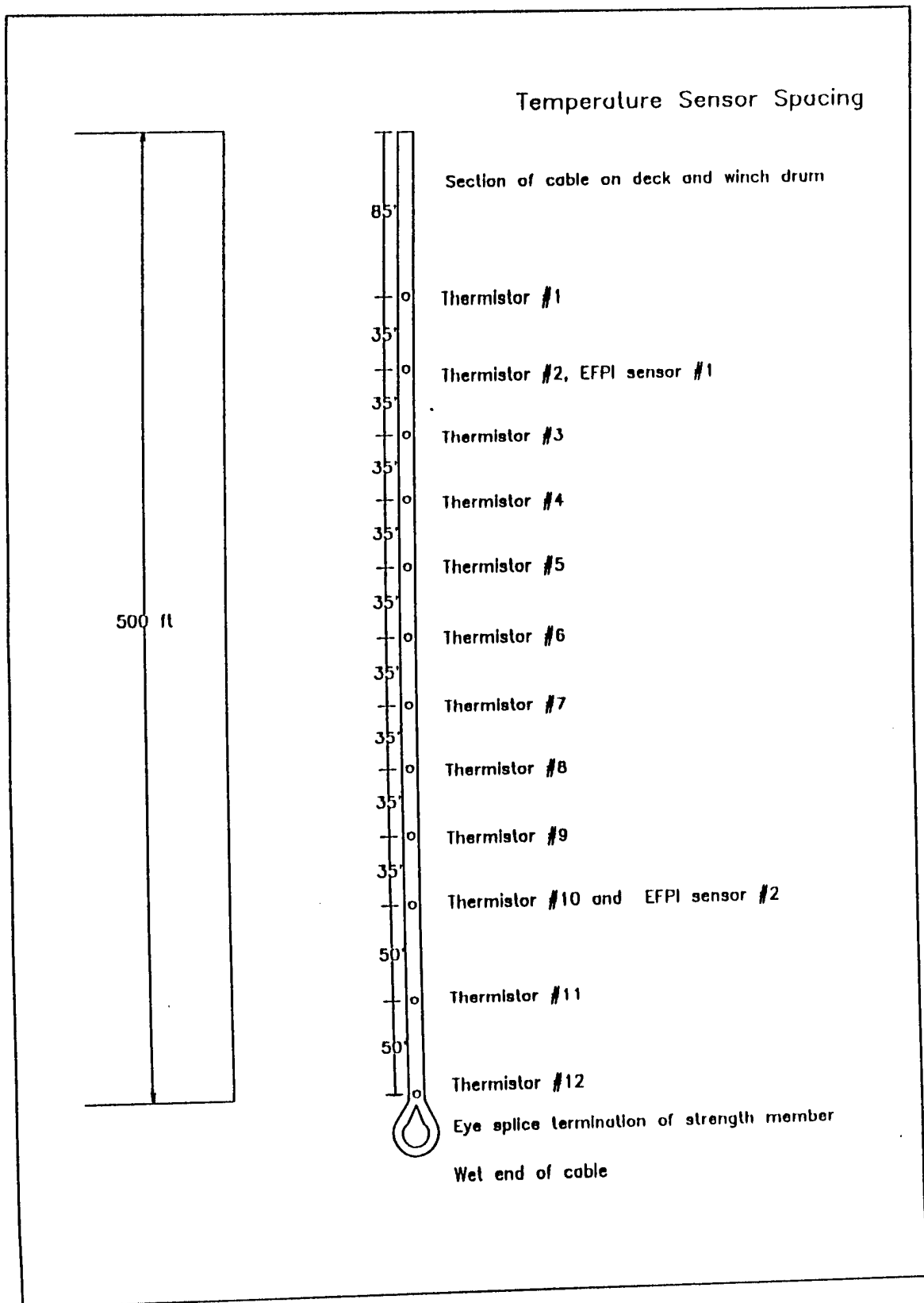
Fabrication Results

Assembly of Cable

Once the optical components had been reinforced and the conductor elements were wound onto braider bobbins the major fabrication step could proceed. Early on it was proposed that the fiber optic elements be fed into the slots parallel, but there was a real concern that such a design would buckle the fibers when bending the cable. It was decided to helix the fiber elements around the core in a shallow spiral. A turntable was set up below the braider to do this. The fiber leads were laid in the slots and taped about every foot as the core entered the braid point where the wires were wrapped around the cable. All of the conductor elements survived the tortuous path over the center eyelet, down to a 180° turn around the braider latch and up through the upper eyelet. Once the braid/serving operation was complete, all the wires were checked for dc resistance and continuity was confirmed for each of the conductors.

Attachment of Thermistors

The thermistors were attached beginning at the bottom end of the cable and working toward the top. Attachment to the #30 awg and #32 awg leads was rather straightforward. The XBT wires proved to be the challenge. Joining the #39 awg leads to the #38 awg leg of the thermistor sensor directly did not work well. There was not enough mass of copper to get the solder to flow. After some experimenting, the best approach turned out to be soldering a #34 awg bare copper jumper wire between these smaller gage wires. After each solder connection, the uninsulated wire was coated with GLPT insulating varnish that dries quickly and provides a flexible skin over the bare wire. After installing the thermistor, Mylar tape was wrapped over the cable for a length of six or eight inches with the thermistor at the center of this section. There were actually a total of 13 pairs of conductors, so twelve were connected to thermistors, one was designated as the common return conductor and the other was left unused.

The diagram on the following page shows the relative location of the thermistors along the length of the cable assembly.

Temperature Sensor Spacing

Section of cable on deck and winch drum

85'

Thermistor #1

35'

Thermistor #2, EFPI sensor #1

35'

Thermistor #3

35'

Thermistor #4

35'

Thermistor #5

35'

500 ft

Thermistor #6

35'

Thermistor #7

35'

Thermistor #8

35'

Thermistor #9

35'

Thermistor #10 and   EFPI sensor #2

50'

Thermistor #11

50'

Thermistor #12

Eye splice termination of strength member

Wet end of cable

Extruding the Outer Jacket

All the thermistor circuits were intact before the outer jacket was applied. An extra hundred feet of cable was available at the bottom end for extrusion start up, the extrusion began at that end of the cable. The process went fine for approximately 450 ft. At this point, the extrusion pellets warmed a bit near the bottom of the feed hopper funnel. This, coupled with the sticky yellow color concentrate pellets resulted in the material clumping together and forming a bridge that prevented the resin from flowing into the hopper. Since this was a short prototype run there was not much resin in the hopper which meant that there was not enough weight of material above this "bridge" to cave it in. With the resin bridge retarding the continuous flow of pellets into the extruder, the barrel was emptied of material and a bare section of cable with no Hytrel jacket resulted. A few raps on the outside of the hopper collapsed the resin bridge and resumed the flow of plastic through the barrel, but restarting the jacket midspan on the cable is a difficult task. The jacketing resin must be compressed onto the cable with pliers so that the hot plastic moves with the cable. The cable suffered some trauma at this point due to pinching and we lost continuity on all of the small XBT wires and some of the larger conductors.

Verifying the Thermistor Circuits

After applying the extruded cover on the cable each of the conductors was checked for dc resistance. The attached chart shows the result of these electrical measurements. The conductor through the thermistor at position #8 was no longer continuous and the return wire from sensor position #11 had a very high resistance (near open circuit). The three XBT circuits also had infinite resistance. Each of the remaining conductors with thermistors in series had readings between 11K and 13K ohms, which is consistent for ambient room temperature (65°F to 75°F).

Fiber Sensor Testing

Following the jacketing operation, representatives from Fibers & Sensors, Inc. came to Cortland Cable to install connectors on the two optical fiber leads in the cable. Subsequent readings indicated that the fibers were both broken between the connectorized end and the EFPI sensors. The fibers were checked from the exposed section of cable (with no Hytrel jacket) and the result was the same (both fibers broken). The upper EFPI sensor at the #2 position was then physically located and the fiber optic lead traced to a point about eighteen inches up the cable and a fiber optic connector was again installed. This time the display indicated a temperature reading on the laptop computer screen. This indicates that the fiber did not break where it exits the protective stainless tube, but that is about all that this good reading reveals. As mentioned earlier, to properly track the component's ability to survive manufacturing, there needs to be a method for monitoring the fiber integrity at each step in the build process.

Post-extrusion checkout -- SBIR Cable -- Job 6450

Sensor	From top	interval	Deck Cable	Lead 1	(to #0)	Deck Cable	Lead 2	(to #0)	Thermistor
#0	Common	return	YELLOW	GR	w/sensor	GREEN	(w/BR.)	return	
1	84	84	PURPLE	OR	12.17K	GREEN	BR	99.7Ω	S/N 18
2	112	28	BLUE	BR	11.05K	SLATE	SL	101.5Ω	S/N 16
3	147	35	BLUE	KXBT	12.19K	PURPLE			S/N 14
4	181	34	SLATE	BK32	13.55K	BL/W&BLK STRIPES	BL32	127.3Ω	S/N 13
5	215	34	W/BLK STRIPE	WXBT	12.24K	RED/BLK STRIPE			S/N 12
6	250	35	G/BLK STRIPE	OR	12.41K	BLK/R&GSTRIPES	BK	105.8Ω	S/N 10
7	285	35	BLK/W STRIPE	GXBT	12.40K	RED/W STRIPE			S/N 9
8	320	35	-----	SL	open	BROWN	GR	100.2Ω	S/N 8
9	354	34	G/W STRIPE	BL32	12.55K	BLUE/W STRIPE	OR	101.8Ω	S/N 6
10	376	22	BLK/RED STRIPE	YE	12.52K	W/RED STRIPE	SL	103.4Ω	S/N 5
11	438	62	BLK	BL32	12.40K	------	GR32	18 megΩ	S/N 3
12	487	49	RED	OR	13.73K	ORANGE	YE	95.1Ω	S/N 2

Shaded wires were connected to conductors in the deck cable's outer layer, with the intent of possibly slitting the deck cable and installing thermistors that could then be molded over. In order to do this, we would want the continuity through to the bottom of the cable and back restored. The two open conductors (Lead 1 to #8 and Lead 2 to #11) were not connected. It was our plan to replace the return lead for the #11 thermistor with the green wire at position #8 where we have lost the sensor connection. The remaining nine active sensors and the common return pair were connected to the 20 conductors of the inner layer of the deck cable extension. The connections to the active sensors followed the order of the wires clocking around that inner layer. These should be a lot easier to connect to your instrumentation.

Additional Thermistor Testing

An open circuit had been recorded for each of the XBT pairs from the top after extrusion. Knowing that the probable damage area was where the jacket was restarted, a check was made on the continuity of the XBT wires from this exposed section. Since the jacket was missing, this was an easy test to accomplish. Continuity was good from this point down to the bottom end of the cable and back - through each respective thermistor sensor. The cable was cut at this point to recover these three sensor assets.

Deck Cable Attachment

To maximize the utility of the prototype cable, an upper extension was spliced to the top end of the prototype. This extra length was a slightly stronger cable with more conductor elements. The deck cable conductors are several gage sizes larger than the fine wires in the prototype, which will facilitate connecting the circuits to the data collection device.

Lesson Learned

As a result of the prototype cable fabrication process, the feasibility of building a cable with embedded sensors connected to fine wire leads has been confirmed. Specifically, the following statements can be made.

Fine wire leads (as small as #39 XBT pairs) can be spiraled around a cable core without damage if wound with supporting strands of synthetic fiber or heavier insulated wires.

Consistent, reliable contact to the individual #39 wires of an XBT pair can best be accomplished by first cooking off the varnish with thermal wire strippers and then soldering the XBT wire to a section of #34 bare copper.

Thermistor sensors must have a minimum lead wire size of #38 awg to be soldered to the leads of a thermistor string cable.

A larger gage bare copper wire (#34 or #32) jumper facilitates the connection of thermistors to very fine lead wires (i.e. #39 XBT pairs) by providing the copper mass needed to transfer heat to the solder so it will melt and flow.

Connected thermistors can survive the application of a pressure extruded outer jacket without loss of circuit continuity.

Fiber optic sensor leads need to be protected in order to survive processing into a cable. A proposed approach would be to begin with a 900 micron tight buffered fiber and install the optical sensor on that protected element. There is no easy way to reinforce a bare fiber once the sensor is attached. Further development is required to establish the feasibility of the optical fiber approach to temperature sensing.

Part B - PBO Fiber Evaluation

PBO fiber braid was compared to both Kevlar and Vectran using the same amount of fiber in the same braid construction. The initial tensile strength of the PBO version was almost double that of the Kevlar braid. Tests were conducted to compare the resistance to abrasion on dry samples and samples with various coatings applied to see which combinations of resin and fiber improved the performance in the abrasion test.

External Abrasion Test Apparatus

One mode of failure for synthetic fiber structures is external abrasion. In order to compare the relative resistance to abrasion of different fiber materials and fiber/coating combinations a test apparatus was built. Attached to this report is a description of the test equipment and a drawing.

Preliminary Abrasion Test Results

When first reviewing the types of coatings available to improve the abrasion resistance of synthetic fiber braids it was learned that there were more options than we could effectively evaluate. A list was developed based upon our past experience with line coatings and suggestions from the fiber producers. To narrow the field, some conveniently sized small braids were selected and an initial series of tests on both Vectran and Kevlar were conducted in an attempt to eliminate some of these coating options early in our test program. Six different coatings were applied to identical lines of Vectran braid and Kevlar braid. Each sample was installed on the abrasion test fixture under a tensile load of approximately 20% of the line's rated strength. The tester slid a smooth 3/4" diameter bar against the line over a stroke length of six inches. The machine cycled each sample at a nominal rate of one cycle per second until the line wore through.

Based upon the initial round of testing, two coating options that did not increase the cycle life of tested samples and two materials that made the coated braid too stiff were eliminated. The most promising candidates were a marine finish used on sail cloth and a wax emulsion. These two materials were applied to each of the fiber braids and evaluated on the external abrasion test fixture.

Baseline Braid Geometry

A baseline of twelve strand braid with a nominal minimum strength rating of approximately 2,500 lbs was selected. This line is small enough to test in our lab on an Instron Tensile Tester and yet big enough to survive several hundred cycles of abrasion under static load during dynamic testing. Each strand of the twelve part braid consisted of 6,000 denier twisted with two turns per inch. The braid was configured so that the helical path of the fiber strand elements is in reverse direction to the strand twist. Therefore, the finished braid has the fibers oriented along the axis of the line.

Rope Abrasion Tester

The ability of ropes, belts, webbing and similar synthetic fiber products to resist external abrasion is critical to many applications. This apparatus provides a means to abrade these products against a variety of surfaces at different radii with the tensile member at either low or high tensions.

The most practical method that can be used in the laboratory to evaluate ropes and similar products for abrasion resistance is to compare one to another after each has experienced the same abrasive procedure. These data can also be compared to field experience. The procedure used with this equipment simulates the type of abrasion that is encountered most often in actual service when relatively high tensions are involved.

Abrasion Test Procedure

Based upon pull tests to failure of new samples of the braided lines of interest, the specimens are loaded to 20% of their ultimate strength. The load is applied hydraulically and maintained at the pre-set level as the machine is running.

A reciprocating fixture with a six inch stroke length is designed to hold a steel bar that can range in size from ½" diameter up to 2" diameter. For our tests a 3/4" round steel bar was used. The six inch stroke length assures that the contact area on the sample includes all of the strands in the braid or the rope being tested.

All of the samples were secured by the same method and loaded to the same proportional tension (20% BS). The machine runs at a nominal rated of one cycle per second, so this parameter was the same for all specimens. All samples were clearly marked indicating the fiber material and type and the coating, if any. Each sample was cycled on the fixture until the tension reading dropped to zero. The number of cycles to failure was recorded for each candidate line.

Abrasion Test Results

To establish a performance baseline against which to compare the new PBO fiber four different fiber materials (Kevlar 29, T961& T960 and Vectran HS, T97 & T150) were evaluated. Each line was tested both dry and with coatings applied. A dry, uncoated sample of each line was tested to establish the nominal strength. The abrasion tester was then set to hold the line at 20% of its rated strength during the abrasion cycling. Attached is a chart of the test results. For most configurations ten tests were run. Some of the Kevlar test results were very consistent, so only five test iterations were conducted. These tests show that Vectran braid outlasts Kevlar in terms of cycles to failure by a factor of at least eight to one, whether dry or coated. It is also interesting to note that the Sailkote finish doubles the cycle life of the Vectran, while the wax coating doubles the life of the Kevlar.

Comparative Abrasion Testing of 2700 lbs ($\pm 2\%$) BS braided lines at 20% RBS load

Fiber	Vectran HS	Vectran HS	Vectran HS	Vectran HS	Vectran HS	Vectran HS	Kevlar 29	Kevlar 29	Kevlar 29	Kevlar 29	Kevlar 29	Kevlar 29
Type	97	97	97	150	150	150	961	961	961	960	960	960
Clg	Dry	SailKote	Wax	Dry	SailKote	Wax	Dry	SailKote	Wax	Dry	SailKote	Wax
1	1140	1495	634	562	1126	577	56	53	128	62	62	83
2	711	965	664	509	1344	578	57	62	117	72	82	84
3	1420	967	655	478	688	564	57	50	137	78	64	70
4	780	1468	686	513	1275	591	59	56	118	65	65	67
5	894	1285	670	534	1023	618	56	51	116	64	63	72
6	775	1164	800	576	1118	621			117			76
7	1086	1295	634	528	827	644			129			65
8	794	1196	746	536	1073	628			129			77
9	748	1236	679	441	912	582			129			60
10	1125	900	650	572	1209	586			124			64
AV:	947	1197	682	525	1060	598.9	57	54.4	124.4	68.2	67.2	71.8
%Δ	100	+26.4	-28	100	+101.9	+14.1	100	-4.6	+118.2	100	-1.5	+5.3

PBO Braid

Late in the performance period the sample quantities of PBO fiber that were ordered in November finally arrived from Japan. This material was processed into a braid identical in geometry to the Vectran and Kevlar braids that had been tested earlier in the contract. At least three abrasion tests were run for each load level with dry fiber and wax coated samples. The chart below shows the results. The tests were run at the same load used for testing the other fibers and at a tension level of about 20% of the cable's strength (double the load of the initial tests). The table compares PBO to Vectran Type 150 and Kevlar 29 Type 961 in both dry, uncoated form and after the application of a wax emulsion coating.

Coating Type	Vectran T150	Kevlar 29 T961	PBO (same load)	PBO (2X load)
Dry	525	57	305.3	32
Wax	599	54	471	73

Conclusion

The data shows that at the same load for a particular cable diameter, PBO outperforms Kevlar in each category. The waxed PBO braid still lasts longer than the waxed Kevlar at twice the line tension. The Vectran material was the best at surviving the abrasion test.

COMMENTS BY WOODS HOLE OCEANOGRAPHIC INSTITUTION

1.) *Summary of Thermistor Cable Development Status*

The significant hurdles in making a workable thermistor cable with additional complexities caused by incorporating two optical fibers were overcome through the dedicated effort of Cortland Cable Company. The outcome is a workable cable with 10 thermistors, each individually hard-wired to the towing point with an additional common return conductor. The thermistors in this cable are responding to local temperature increases with instant readout responses. However a calibration of the experimental cable, although originally planned, has been postponed until a Phase II contract is in place. Also postponed for a Phase II effort is handling and other compatibility testing of the completed cable, and the development of terminations. Significant detail design issues have to be further addressed. These include the type and size of thermistor, acceptable readout tolerance levels, handling systems design requirements, the tradeoff between cable size and optical fiber macrobending limits, electrical conductor and sensor element survivability.

It is appropriate at this time to look into the feasibility for use of the thermistor cable just completed. Depending on the strategic requirements for the mission of a thermistor carrying cable it is important to focus on the cable sensing requirements. Additionally the limits of cable, thermistor, and optical fiber endurance under operating and survival conditions have to be evaluated. The following alternatives could be considered:

2.) *TARS Tow Cable with Thermistors*

Incorporation of thermistors into the regular TARS heavy and neutral buoyant tow cable is one option. The ability to do this is however quite limited. Diameter increases are not permitted due to the already cramped storage space conditions of the TARS towed array on the cable handling system. The outer cable jacket with about 0.1 inch wall thickness seems to be not suitable to serve as a support for thermistor conductors and sensors. There is no physical space, and the point pressure during retrieval of the TARS system at high speeds creates pressure between the cable and the small diameter level-wind rollers in the order of 30,000 psi. This pressure is barely supported by the undisturbed HDPE jacket. Unless a major breaking strength reduction of the tow cable can be justified, which would allow for a smaller armor package, there is no room to accommodate the wire leads and thermistors in a protected and survivable manner. It seems to be of little benefit to incorporate thermistors into the neutrally buoyant portion of the TARS two cable, since identical temperature measurements can be made in the towed array section at the same water depth.

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3.) *Separate Thermistor Tow Cable*

A tow cable equipped with thermistors, such as produced under this SBIR contract by Cortland, can be manufactured readily with a temperature readout tolerance of +/- 0.1 degrees Celsius. Smaller readout tolerances may be achievable with effort and time. However the location of the individual thermistor in the water column has to be known in order to permit a correlation between water depth and temperature. Since precise hydrodynamic modeling methods are required to predict location of thermistors with known spacing along the cable length, the modeling tolerance has to be determined and known. The combination of tolerances for temperature readout and predicted hydrodynamic cable position has to be known to assess the utility of the temperature recording. Direction from the Navy should determine if the current prototype cable has sufficient sensing capability for towed array operations and would justify the development of its own winch, handling, and data processing system; or if other uses for this cable would be content with thermistor readouts alone.

Special thermistor cables with their own handling system were developed in the 1960s. Thirty and more thermistors were mounted 25 ft apart into fairings, connected to a 830 ft long chain, which was stored in a single layer on a large winch drum. The conductors leading from the thermistors to the ship were protected in grooves inside the chain. The entire system, mounted on board the USS Marysville of San Diego, weighed 37,500 lbs, connected to a 2,300 lbs heavy fish which tows at 750 ft depth while sailing at 6 knots (1). A similar installation was on board the R/V Chain and was used extensively in cruises in the Atlantic and Mediterranean (2)(3)(4).

4.) *Cables Measuring Temperature, Conductivity, and Depth*

For optimum sonar performance ocean water temperature readouts are most useful if they are combined with measurements of the depth and location relative to the towing vessel in the water column, and if the salinity (conductivity) of the sea water is known as well.

Each sensor element is a combination of a thermistor, and sensors to measure conductivity and hydrostatic pressure (depth). Methods to develop a cable would utilize either a two-wire or four wire harness, plus two power conductors in each case, to connect the sensor elements to the ship's receiver. The two-wire harness would use the RS-485 protocol, the four-wire harness the RS-422. Cable lengths of several kilometers would be possible, even at substantial bit rates. The maximum number of sensing elements without repeaters is 32. Ultra-small flexible circuitry would be needed to embed each sensor into the cable (5)(6). The manufacturing of such a cable would be very challenging. It may require production in 25 ft long sections, connected to each sensor and circuitry element, until continuous length manufacturing methods have been developed.

Inductive coupling of sensor elements to a central insulated wire rope, using sea water return, would be an alternative which would avoid the difficulties of conductor harnesses in the cable. However the inductive "pods" are typically 2 to 4 inches in diameter, hardly suitable for normal reeling and storage of a cable with pods on a winch drum. This technique is being used successfully on buoy moorings, where the need of retrieval and storage on winch reels is not a requirement (7).

A small independent cable deployment system for CTD profiling has been developed. Data collection at speeds up to 12 knots and up to 110 meter depth have been demonstrated (8). The system drops a cable suspended profiler and retrieves it back onto the ship with a small autonomous winch and an overboarding boom, the operation is autonomous and controlled by computer. However such a system would sample data once at every drop and retrieval, lasting several minutes, it does not allow continuous data collection.


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(4)   Hersey, J.B., Bunce, E.T., (1964); "Narrative of Chain Cruise #34",
         Woods Hole Oceanographic Institution Reference No. 64-35

(5)   Prada, K., WHOI staff, personal communication (1997)

(6)   Valdes, J., WHOI staff, personal communication (1997)

(7)   Frye, D.E. et al. (1996); "The Atlantic Long Term Oceanographic Mooring
         (ALTOMOOR), WHOI Technical Report 96-02.

(8)   Moving Vessel Profiler, by Brooke Ocean Technology, Halifax, NS (1997).

Contributed by W. Paul, WHOI, 6-26-97
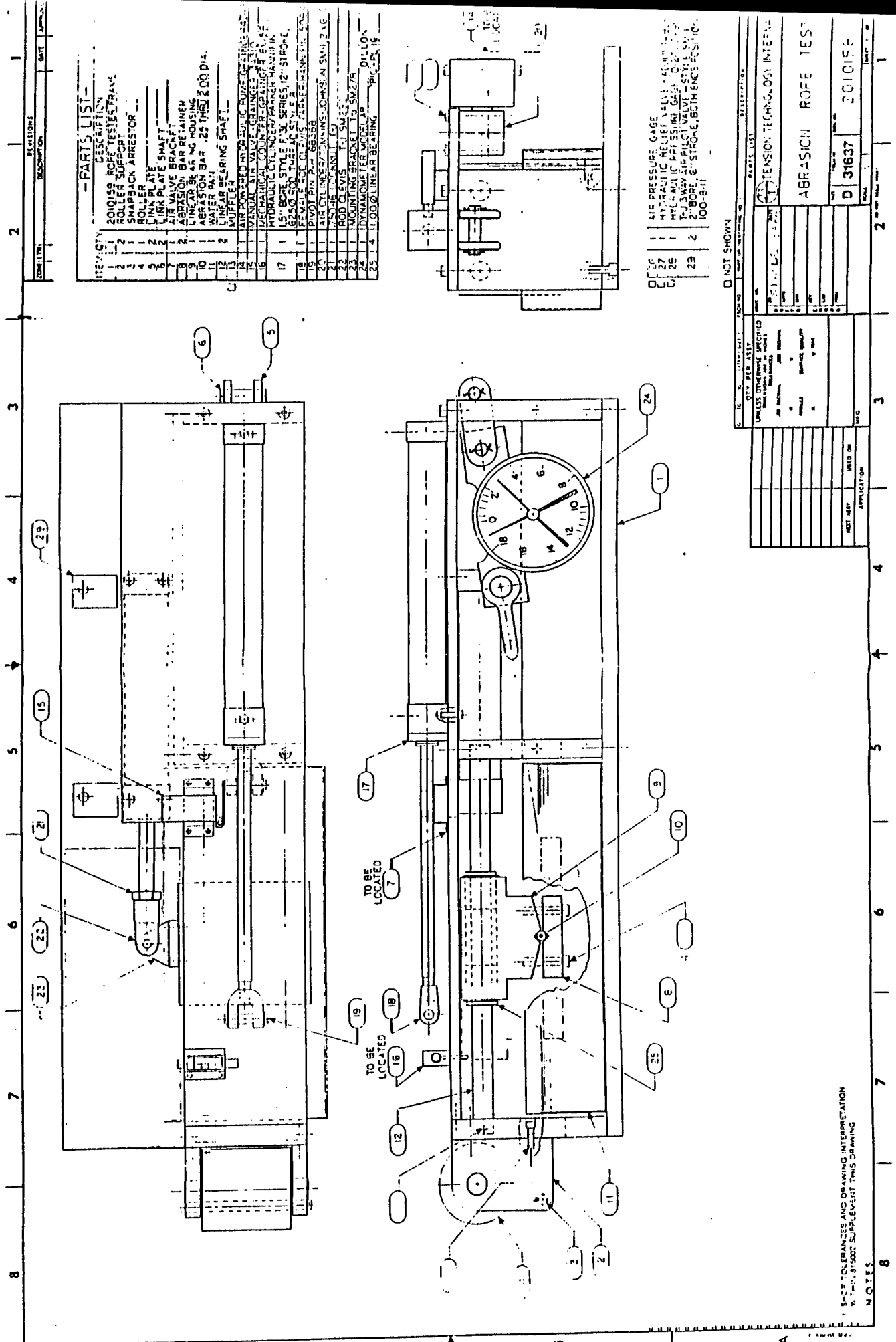
PARTS LIST

ITEM	QTY	DESCRIPTION
1	1	20Q159 ROPE TESTER FRAME
2	1	ROLLER SUPPORT
3	1	SNAPBACK ARRESTOR
4	1	ROLLER
5	2	LINK PLATE
6	2	LINK PLATE SHAFT
7		AIR VALVE BRACKET
8	2	ABRASION BAR RETAINER
9	2	LINEAR BEARING HOUSING
10	2	ABRASION BAR .25 THRU 2.00 DIA.
11		WATER PAN
12	2	LINEAR BEARING SHAFT
13		MUFFLER
14		AIR POWERED HYDRAULIC PUMP OR ...
15		MANUAL AIR VALVE - GRAINGER ...
16		MECHANICAL COUNTER - GRAINGER 6X... SE
17		HYDRAULIC CYLINDER / PARKER-HANNIFIN
		1.5" BORE STYLE F3H, SERIES, 12" STROKE
		6250 PSI ON THE ... ACT....
18		FEMALE ROD CLEVIS, CLEVIS LENGTH 5.0
19		PIVOT PIN 2 ... 66558
20		AIR CYLINDER / CUMMINS-JOHNSON SN-1 21G
21		...
22		ROD CLEVIS T-J SM...
23		MOUNTING BRACKET T-J SM27A
24		DYNAMOMETER MODEL AP DILLON
25	4	11.00Q LINEAR BEARING PIC-PL-19

26	1	AIR PRESSURE GAGE
27	1	HYDRAULIC RELIEF VALVE - 4000 ...
28	1	HYDRAULIC PRESSURE GAGE 0-2...
		T-J 3 WAY AIR PILOT VALVE - STYLE SM...
29	2	2" BORE, 6" STROKE, BOTH ENDS POSITION
		100-8-11

☐ NOT SHOWN

UNLESS OTHERWISE SPECIFIED

NOTES:
1. SHEET TOLERANCES AND DRAWING INTERPRETATION
   PER ... 81500Z SUPPLEMENT THIS DRAWING

TO BE LOCATED

TO BE LOCATED

DESCRIPTION OF ROPE ABRASION TEST APPARATUS

For the description of the rope abrasion test apparatus refer to TTI Drawing No. 2010150. The device is self contained and is about 42 inches long by 12 inches wide and 10 inches high. It is operated by up to 90 psig air pressure, requiring only a single air connection.

A mechanical tension dynamometer records tension and a mechanical counter records abrasion cycles. Maximum load is 4000 lbs and the scale has 25 lb divisions. Zero adjust and maximum load indicator are provided.

A 2 inch bore air operated cylinder moves a carriage back and forth. The carriage holds the abrasion tool; the test specimen wraps around the tool with an angle of 20°. The cylinder contains built-in air controls that automatically reverse the carriage at the ends of the 6 inch stroke. Carriage speed is adjusted by flow controls on each of the two ports on the cylinder. The carriage moves on low friction, linear ball bushings. A single ball valve, marked "Carriage" starts and stops the Carriage.

A 1.5 inch bore hydraulic ram provides tension to the rope specimen. Hydraulic fluid is provided at pressure to 3000 psi by an air operated booster pump. The pump is mounted on the back of the apparatus, under the air cylinder. Maximum pressure is set by an adjustable relief valve in conjunction with a pressure gauge. A ball valve marked "Ram" applies pressure to the Ram and another ball valve marked "Ram Release" allows the Ram to be pulled out or retracted by hand.

Air pressure to a booster pump develops hydraulic pressure to the Ram to apply tension to the rope under test. A precision regulator, marked "Air Reg" is provided for air pressure control to set tensions from 400 lbs to 4000 lbs. The Pump is set to stall when the test tension is reached.

A removable water pan fits under the abrasion tool and will submerge it and the adjacent portion of the rope for wet testing.

An air shut off valve is actuated by the clevis on the end of the rod of the tensioning cylinder. This will stop the machine when the rope fails. This valve can also be operated manually and will shut off the air supply to the entire apparatus.

The test apparatus will fit on a laboratory bench. It requires only a connection to a supply of filtered, dry, compressed air. It may be operated from 20psi to 125psi input pressure; however, ram tensions will be limited if input pressures are low. Should the required air supply not be available, a very small, inexpensive, portable electrically powered air compressor (½ hp, 1.7 CFM @ 90 psig) unit could be used in conjunction with the test device.